Comparative study on active soil organic matter in Chinese fir plantation and native broad-leaved forest in subtropical China

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Abstract: Active soil organic matter (ASOM) has a main effect on biochemical cycles of soil nutrient elements such as N, P and S, and the quality and quantity of ASOM reflect soil primary productivity. The changes of ASOM fractions and soil nutrients in the first rotation site and the second rotation site of Chinese fir plantation and the native broad-leaved forest were investigated and analyzed by soil sampling at the Huitong Experimental Station of Forestry Ecology (at latitude 26°48'N and longitude 109°30'E under a subtropical climate conditions), Chinese Academy of Sciences in March, 2004. The results showed that values of ASOM fractions for the Chinese fir plantations were lower than those for the broad-leaved forest. The contents of easily oxidisable carbon (EOC), microbial biomass carbon (MBC), water soluble carbohydrate (WSC) and water-soluble organic carbon (WSOC) for the first rotation of Chinese fir plantation were 35.9%, 13.7%, 87.8% and 50.9% higher than those for the second rotation of Chinese fir plantation, and were 15.8%, 47.3%, 38.1% and 30.2% separately lower than those for the broad-leaved forest. For the three investigated forest sites, the contents of MBC and WSOC had a larger decrease, followed by WSC, and the change of EOC was least. Moreover, soil physico-chemistry properties such as soil nutrients in Chinese fir plantation were lower than those in broad-leaved forest. It suggested that soil fertility declined after Chinese fir plantation replaced native broad-leaved forest through continuous artificial plantation.

Keywords: Active soil organic matter; Chinese fir plantation; Native broad-leaved forest; Soil nutrient elements

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Introduction

Soil organic matter (SOM) is as important as a reservoir of nutrients such as nitrogen, phosphorus and sulphur. It also contributes significantly to the formation and stabilization of soil structure. However, it is difficult to detect subtle changes in the quality of SOM in a short term or medium term because of the large amount of organic matter in soils and the spatial variability of soils, especially in forest soil (Bosatta *et al.* 1994; Bolinder *et al.* 1999). Active soil organic matter (ASOM) is the heterogeneous mix of living and dead organic materials (Wander *et al.* 1994), including microbial biomass carbon (MBC), easily oxidisable organic carbon (EOC), water-soluble organic carbon (WSOC), and water soluble carbohydrates (WSC) measured as anthrone-reactive carbon. As active fractions are usually more easily affected than total soil organic carbon (TSOC) by management, measures of them can be used as early indicators of change in SOM status (Gregorich *et al.* 1994; Bremer *et al.* 1994).

Chinese fir (*Cunninghamia lanceolata*) is a main tree species in southern China. The timber production of this species plays a very important role in the national forestry economy. However, the prevailing soil degradation due to Chinese fir monoculture and continuous cropping has now become a serious problem in further exploiting this valuable resource of timber. Thus, it is important to study the changes in ASOM under continuous cropping for the purpose of reducing soil degradation or improving soil quality in the region. There were only few reports about the active soil organic matter (Xu *et al.* 2003; Jiang *et al.* 2002).

The objective of this study is to determine the change of ASOM after Chinese fir replaced the native broad-leaved forest through continuous man-made plantation in subtropical China.

Materials and methods

Study site

The study was conducted at the Huitong Experimental Station of Forestry Ecology, Chinese Academy of Sciences in March, 2004, which is located at latitude 26°48'N and longitude 109°30'E under a subtropical climate conditions. The mean annual temperature is 16.5℃ and the annual precipitation is about 1 240 mm. According to Chinese Soil Taxonomy, alfisol is the principal soil type, and dominantly developed from the parent rocks of slate and shale. The native vegetation is the typical subtropical evergreen broad-leaved forest, mainly composed of *Castanopsis and Lithocarpus*. However, Chinese fir plantation or masson pine forests have become the major forest communities currently because the zonal forest community has almost been destructed by human activities.

Soil sampling

Ten random soil cores at a depth of 10 cm in native broad-leaved forest (NBF) and in the first rotation of Chinese fir plantation (FCF) and the second rotation of Chinese fir plantation (SCF) were taken by using a 45-mm-diameter tube sampler to form a composite sample for each replicate. Three independent replicates were taken at each site. Visible roots and organic residues were removed at the sampling time. Each sample was

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divided into two parts. One was stored at 4℃ for analysis of microbial biomass C and water-soluble organic C. The other part of the soil was air-dried, and then was ground for determination of total soil organic C, easily oxidisable C, water soluble carbohydrate and soil physico-chemistry properties.

Soil analysis

Soil pH was measured by using a glass electrode with a soil/water ratio of 1:2.5. Soil special gravity was determined by the pycnometer method. Total N in extract was determined by semi-micro Kjeldahl digestion. Determination of NH_4^+-N in the digests was based on the phenol-hypochlorite reaction. Total P, total K, available P and K were tested according to methods described by ISSCAS (1978). Water-soluble organic C was extracted from a 10-g fresh soil in addition to 25 mL distilled water (Liang *et al.* 1998). Microbial biomass C was determined by using the chloroform fumigation-extraction method, and calculated as the difference between fumigated and unfumigated samples divided by the K_2SO_4 extract efficiency factor of 0.38 (Vance *et al.* 1987). Organic C in the solution was measured by Total Organic Carbon Analyzer (High TOC II +N, Elementar). The easily oxidisable C was determined by dichromate oxidation method (Liu, 1996). TOC was measured by Total Organic Carbon Analyzer (High TOC II +N, Elementar).

Results and discussion

Soil physicochemistry properties

Contents of the soil total nitrogen and NH_4^+-N were also observed comparatively. They were highest in NBF and lowest in SCF. The concentration of soil total N in SCF was 19.8% lower than that in FCF and 40.6% higher than that in NBF (Table 1). Moreover, the content of soil available N in SCF was much lower than in FCF and NBF. The contents of total P and available P in SCF were comparatively lower than those in the other two forest types. However, the contents of total P and available P were little higher FCF than those in NBF. The contents of total K and available K between FCF and NBF did not differ. These results were consistent with those observed by Wang *et al.* (2000), who reported that the contents of soil nutrients including NH_4^+-N, NO_3^--N and available P in the broad-leaved forest were higher than in Chinese fir plantation at the Huitong Experimental Station of Forestry Ecology, Chinese Academy of Sciences. There was little difference in soil specific gravity between the three experimental forest sites (Table 1). Among the three forest sites, the maximum soil specific gravity was noticed in SCF and the minimum soil specific gravity in NBF. Change of soil pH was not evident for the three sites, with a range from 4.43 to 4.73.

Table 1. Soil physico-chemistry properties under different forest sites

Forest sites	Total N /g·kg^{-1}	NH_4^+-N /mg·kg^{-1}	Total P /g·kg^{-1}	Available P /mg·kg^{-1}
the native broad-leaved forest (NBF)	2.66 (0.80)	16.99 (1.76)	0.23 (0.04)	0.71 (0.10)
the first rotation of Chinese fir plantation (FCF)	1.97 (0.40)	12.15 (4.27)	0.27 (0.01)	0.83 (0.14)
the second rotation of Chinese fir plantation (SCF)	1.58 (0.22)	8.36 (1.91)	0.19 (0.02)	0.73 (0.49)
Forest sites	Total K /g·kg^{-1}	Available K /mg·kg^{-1}	pH (H_2O)	SSG /g·cm^{-3}
the native broad-leaved forest (NBF)	35.82 (1.23)	215.76 (7.79)	4.66 (0.23)	2.417 (0.102)
the first rotation of Chinese fir plantation (FCF)	33.66 (0.69)	217.96 (27.88)	4.43 (0.11)	2.430 (0.037)
the second rotation of Chinese fir plantation (SCF)	22.94 (0.12)	175.58 (43.39)	4.73 (0.07)	2.544 (0.083)

Notes: Standard deviations (in parentheses) are listed; SSG: Soil special gravity.

Total soil organic C and easily oxidisable organic C

The soil organic carbon plays important roles in soil conservation and global environmental changes (Gregorich *et al.* 1994). The content of total soil organic C had no not significant ($p<0.05$) between the FCF (mean 37.8 g·kg^{-1}) and the NBF (mean 39.2 g·kg^{-1}), .but the content of total soil organic C in SCF (mean 24.7 g·kg^{-1}) was 37.0% and 34.7% separately lower than that of NBF and FCF (Fig. 1). Soil organic matter, which is positively related to soil fertility as reported by many researchers (*e.g.* Hayes and swift, 1978), is controlled by many factors, such as soil nature, land use and management practices. Burning and site preparation usually cause a decrease in total soil organic C (Ma *et al.* 1997, 2000) because human activities stimulate mineralization of soil organic matter and soil erosion. It is the case that the content of total soil organic C of SCF was significantly lower than that of NBF and FCF in this study.

Easily oxidisable organic C as an active fraction of soil organic matter is easier to be affected by management practices. Similar to total soil organic C, the mean contents of easily oxidisable organic C for FCF (mean 18.8 g·kg^{-1}) and SCF (mean 13.8 g·kg^{-1}) was 15.8% and 38.1% separately lower than that of NBF (mean 22.3 g·kg^{-1}) (Fig. 1). The differences in easily oxidisable organic C between FCF and NBF, and between SCF and NBF reached a significant level ($p<0.05$). Easily oxidisable organic C calculated as a percentage of total soil organic carbon (EOC: TSOC (%)) was 56.92% for NBF, 49.71% for FCF and 55.99% for SCF (Table 2). It is suggested that Chinese fir plantation retained the turn of refractory compounds into labile components due to the fact that Chinese fir litter contained more slowly decomposable compounds and had higher C/N ratio than broad-leaved forest litter (Liao *et al.* 1999). The labile C fraction can be greatly affected by human activities (Torsten *et al.* 2002). Human activities also resulted in the decrease of easily oxidisable organic C.

Microbial biomass C and water soluble carbohydrates

Microbial biomass, which is the most active fraction of soil organic matter, acts as a source and sink of available nutrients and plays a critical role in nutrient conservation in tropical zone (Diaz-Ravina *et al.* 1993; Singh *et al.* 1989). Being a major energy of microorganism, soil organic carbon has a positive relation with microbial biomass C (Haynes 2000). The similar trends to easily oxidisable organic C were observed for microbial biomass C (Fig. 2). Microbial biomass C for FCF (mean 421.73 mg·kg^{-1}) was 47.3% lower than that of NBF (mean 800.51 m g·kg^{-1}), but 13.7% higher than that of SCF (mean 370.92 mg·kg^{-1}). In this study, vegetation type showed a marked differ-

ence in microbial biomass C content in accordance with the results of Hu *et al.* (1991). There existed the significant difference in content of microbial biomass C between FCF and NBF, and between SCF and NBF. The percentage of microbial biomass C of NBF (2.04%) was the highest among the three forest sites, followed by the SCF (1.50%), and that of FCF was the lowest (1.12%). This indicated that soil organic matter was more available for microorganism under broad-leaved forest than that of Chinese fir plantation.

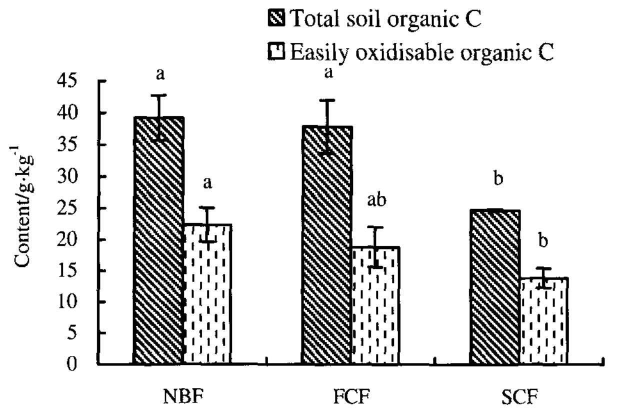

Fig. 1 Contents of total soil organic C and easily oxidisable organic C of soils under native broad-leaved forest (NBF), first rotation of Chinese fir plantation (FCF), and second rotation of Chinese fir plantation (SCF)

Notes: Different letters on the top of the bars with the same pattern indicate significant difference at p<0.01.

Table 2. EOC, MBC, WSOC and WSC as percentage of soil organic carbon or matter

Forest sites	EOC/TSOC (%)	MBC/TSOC (%)	WSOC/TSOC (%)	WSC/SOM (%)
NBF	56.92	2.04	0.92	0.33
FCF	49.71	1.12	0.67	0.21
SCF	55.96	1.50	0.68	0.17

Notes: EOC---Easily oxidisable organic C; TSOC--- total soil organic C; MBC--- Microbial biomass C; WSOC--- Water-soluble organic C; WSC--water soluble carbohydrates; SOM-- Soil organic matter; NBF-- native broad-leaved forest; FCF-- first rotation of Chinese fir plantation; SCF--second rotation of Chinese fir plantation

Soil carbohydrates play an important role in soil aggregation (Cheshire 1985). As shown in Fig. 2, the mean content of water soluble carbohydrates of soil in NBF (mean 220.14 mg·kg^{-1}) was 1.62 times higher than that in FCF (mean 136.27 mg·kg^{-1}) and 3.03 times higher than that in SCF (mean 72.55 mg·kg^{-1}). Carbohydrates are a major source of energy for soil microorganisms (Sparling 1992), and our site shows that there is a strong correlation between microbial biomass C and water soluble carbohydrates. The percentage of soil organic C reflected in water-soluble carbohydrate (WSC: TSOM (%)) was 0.33% for NBF, 0.21% for FCF and 0.17% for SCF (Table 2). This result was lower than the results of Haynes *et al.* (1993). It is well known that soil carbohydrate is important binding agent for aggregation. Therefore, we could infer that the physical structure of broad-leaved forest soil is better than that of Chinese fir plantations.

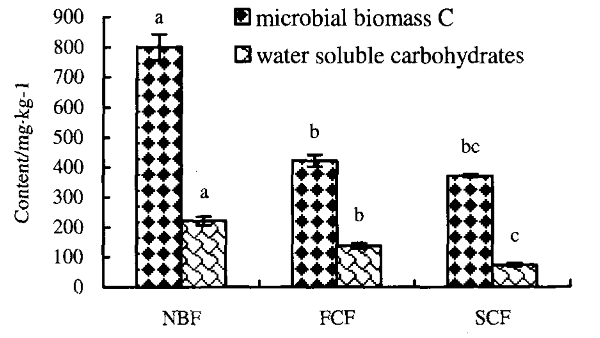

Fig. 2 Contents of Microbial biomass C and water soluble carbohydrates of soils under native broad-leaved forest (NBF), first rotation of Chinese fir plantation (FCF), and second rotation of Chinese fir plantation (SCF) .

Notes: Different letters on the top of the bars with the same pattern indicate significant difference at p<0.01.

Water-soluble organic C

The water-soluble organic C in soils, composed mainly of low molecular substances such as organic acids sugars and amino acids and high molecular substances (Herbert *et al.* 1995), plays an important role in the biogeochemistry of C and in the transport of pollutants in soils. Our study showed that the SCF had the lowest content of water-soluble organic C (range 163.71-172.67 mg·kg^{-1}, mean 167.12 mg·kg^{-1}), compared with the other two forest sites (Fig 3). The difference in content of water-soluble organic C in soils under different forest stands may be resulted from the ability of soil adsorption and pH value. The concentration of water-soluble organic C in mineral soils appears to be primarily related to the ability of soil horizons to adsorb water-soluble organic C (Dalva *et al.* 1992). However, the changes in soil pH were irregular (Table 1). The difference among them reached statistical significant level (p<0.01). Water-soluble C as a percentage of total soil organic C (WSOC: TOSC (%)) was 0.67% for FCF, 0.68% for SCF and 0.92% for NBF (Table 2). It suggested that human practices inhibit the conversion from stable organic matter to labile WSOC fraction.

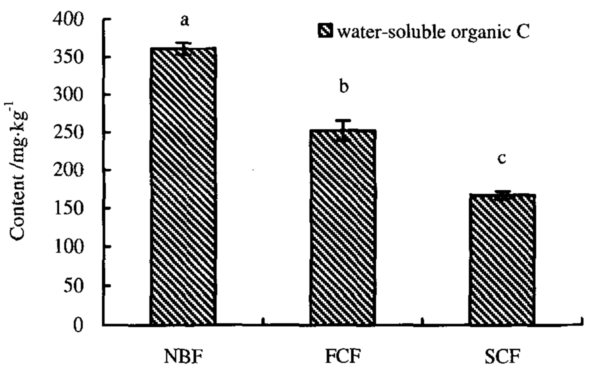

Fig. 3 Contents of water-soluble organic C of soils under native broad-leaved forest (NBF), first rotation of Chinese fir plantation (FCF), and second rotation of Chinese fir plantation (SCF).

Notes: Different letters on the top of the bars with the same pattern indicate significant difference at p<0.01.

Conclusions

Vegetation types and management practices affected the fractions of active soil organic matter. When Chinese fir substituted the native broad-leaved forest and was continuously planted, the decreases in total soil organic C, easily oxidisable organic C, microbial biomass C, water soluble carbohydrates and Water-soluble organic C content were detected. It could be concluded that the replacement of Chinese fir plantation for broad-leaved resulted in a decline of active soil organic matter and soil fertility. This phenomenon was observed when Chinese fir was continuously cropping. In addition, the decline of soil nutrients indicated soil degradation too. Thus, Chinese fir monoculture and continuous cropping should be avoided in order to maintain soil fertility in the future.

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